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Performance of regional climate model and climate change impacts on rainfed maize: case of DMR ESR W variety in the district of Bohicon in Benin

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Abstract:
This study evaluated the ability of regional climate models to reproduce the observed climatology and the impacts of climate change on rain-fed maize in the district of Bohicon in Benin for two horizons: 2030 and 2050. The observed climate data and ten CORDEX Regional Climate Models data in their historical and projected parts were used under scenarios RCP4.5 and RCP8.5.For regional climate evaluation, seasonal cycles were analyzed in addition to statistical metrics (correlation, RMSE, and variance) to verify good agreement between the models and observations. Regarding climate change impacts, a biophysical model (AquaCrop) was used. The results showed that MIROC, MOHC, and NCC reproduced Bohicon's climatology to a certain extent. Taking into account these three models, the average temperature will increase on average from 0.8°C to 1.4°C for RCP4.5 and from 1°C to 1.8°C for RCP8.5 by 2030. The warming will be more pronounced by 2050 for RCP8.5: 1.7°C to 2.8°C. The precipitation is highly variable. According to the MIROC model, regardless of the scenario considered, an increase of 20% in precipitation is expected by 2030, but the MOHC and NCC models predicted that precipitation will be constant. The DMR ESR W variety of maize is affected by climate change. A shortening of its cycle of at least four days is expected. This shortening reached 10 to 12 days in the MIROC and MOHC models, and the yield reductions reached 8 to 14% on average in RCP8.5 by 2050.
Keywords-*Climate change, AquaCrop, maize, DMR-ESR-W, Bohicon*

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I. Introduction

In Benin, the agricultural sector is mainly rainfed and constitutes one of the pillars of its national economy. It contributes 32.7% on average to the Gross Domestic Product (GDP), 75% to export revenues, 15% to country revenues and provides around 70% of jobs [1]. Efficient exploitation of this sector’s potential could improve national economic growth and help to reduce poverty[1]. Unfortunately, this sector has been facing climate change effects, such as the late onset of rainy season, the floods, the dry spells in the rainy season, the early end of the rainy seasons, the heavy rainfall and high winds [2-3]. In addition, climate projections predict an increase in these adverse effects of climate change [4]. Under these climate change effects and global warming, agricultural activities will be more impacted [5]. This situation will considerably affect the Beninese economy and its progress towards food self-sufficiency. In this context, climate change impacts studies in the agricultural sector are necessary because they will allow appropriate decisions to be taken upstream to reduce poverty in the medium and long term and guarantee food security [6]. According to [7], the approaches to carry out these impact studies vary according to the authors and could be classified into three groups:(1) long-term agricultural experimentation, (2) dynamic soil-water-crop modeling and (3) probabilities analysis of dry period’s occurrence in relationship with the needing water of crops. However, [8] hasshown that soil-water-crop modeling is the most recommended approach because it allows better simulation of the response of crops to climatic variations. In Benin Republic, several climate change impact studies have been carried out in the agricultural sector [9, 10, 11], but few have addressed the dynamic modeling which relatedto soil-water-crops. Among these studies, one can cite, for example, [12] have used the crop model Agricultural Production Systems Simulator (APSIM);[13] and [14] have used the Decision Support System for AgrotechnologyTransfer (DSSAT) model. Among these studies, only one [13] considered the South of the country. However, the cultural model that we intend to use in our study is different from that used by these authors. This will provide new sources of information for agricultural and political decision-making in southern Benin

In Benin republic maize (Zea mays) is the most cultivated cereal due to its area and production, it is found on almost all farms. In southern Benin, maize is the important cereal used by the populations [15]. It's the most exported cereal to certain regional markets such as Gabon, Congo and Niger [16]. In this context, assessing the climate change impacts on maize would be of great importance in the economic and nutritional sectors.

This study aims to assess the climate change impacts on rainfed maize in the Bohicon district in Benin using data simulated by some regional climate models and the AquaCrop bioclimatic model. Climate change expected in Bohicon for the horizons 2030 and 2050 and their impacts on the maize cycle length and its yield will be evaluated. This paper is structured as follows: Section 2 describes the data sets and methods involved, results are presented and interpreted in Section 3, and a summary with concluding remarks forms and outlook for further research in Section 4.

II. Study Area

Bohicon district is between 06.55° and 07.08° North latitude, 1.58 ° and 02.24 ° East longitude and is located in the Department of Zou in the Benin Republic. It is limited: to the north by the communes of Djidja and Zakopta, to the south by the commune of Zogbodomey, to the east by the commune of Zakpota and to the west by the communes of Abomey and Agbangnizoun (figure 1). The commune of Bohicon, according to the National Meteorological Agency of Benin, enjoys a transitional subequatorial climate, characterized by two rainy seasons (mid-March to mid-July and September to November) and two dry seasons (mid-July to August and December to March). In the climatology reference period, 1981-2010, the rainfall amounts to an average of 1146.8 mm per year. The coolest month of the year is August with average temperatures varying between 25 ° C and 26.5 ° C. February and March are the hottest months with average temperatures of around 32 ° C. The soil is made up of a vast, homogeneous clay-sandy and sandy loam. The soil shows great physical homogeneity. The water reserve in these soils is substantially constant and varies between 40 and 50 mm at 30 cm from the ground then between 60 and 70 mm at 60 cm from the ground [17].

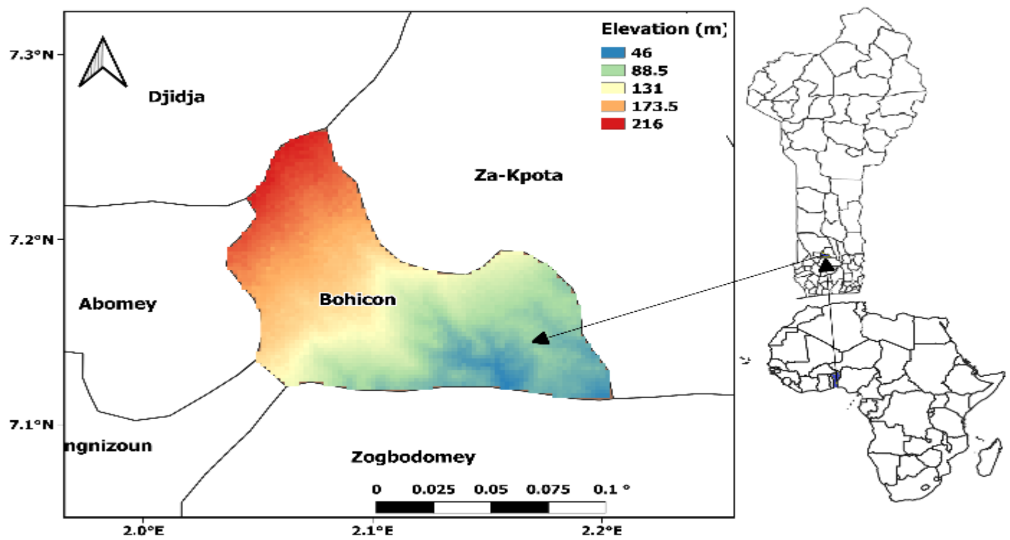

Figure 1: study areawith elevation

III. Data and Methods

a. Data

i. Observed and Regional climate models data

The daily precipitation data, temperature (maximum and minimum), humidity (maximum and minimum), wind speed and sunshine hours for the National Meteorological Agency of Benin (METEO-BENIN) during the period 1954-2016 at the Bohicon synoptic station are used. They are the reference data in this study. According to the regional climate models data, daily temperature, potential evapotranspiration and precipitation data from ten (10) regional climate models from the CORDEX program (Table 1) at 0.44 °x0.44 ° spatial resolution are used. The climate models data are used for two horizons: 2030 and 2050.The historical(control) period is 1981-2000 for all models.

Table1: Regional Climate Models

Name	**Institut**	**Country**
CCCma-CanAM4	CCCma	Canada
CNRM-CM5	CNRM	French
CSIRO-QCCCE	CSIRO-QCCCE	USA
ICHEC-EC-EARTH	ICHEC	Ireland
IPSL-IPSL-CM5A-MR	IPSL	French
MIROC-MIROC5	MIROC	Japon
MOHC-HadGEM2-ES	MHOC	Brazil
MPI-M-MPI-ESM-LR	MPI-M	Germany
NCC-NorESM1-M	NCC	Norvège
NOAA-GFDL-ESM2M	NOAA-GFDL	USA

Source: www.cordex.org

ii. Agronomic data

The maize variety DMR-ESR-W developed by the International Institute of Tropical Agriculture (IITA) and declared sensitive to drought according to the National Agricultural Research Institute of Benin [18] is used as plant material. Its cycle is 90 days. It is cultivated under direct sowing with spacings of 0.80 m between rows and 0.40 m between pockets, i.e., a density of 62,500 plants per hectare for two seeds per pocket [19]. It flowers 48 days after sowing. Its potential yield is 4 tons per hectare in the station and 3 tons per hectare in rural areas [18]. Its harvest index can reach 51% under favorable conditions [20]. We used the observed yield data for the Direction of Agricultural Statistics of Benin (DSA). They cover the period 1996-2016 and will beused to calibrate the AquaCrop Model.

Aquacrop is a bioclimatic model. It is a decision support tool that aims at strategic planning via the improvement oh water productivity in agricultural production. This approach describes the relationship between the yield of a crop and water stress as result of too little rainfall and an insufficient dose of irrigation during the growing period. The relationship between the different inputs of AquaCrop model is shown at figure 2.

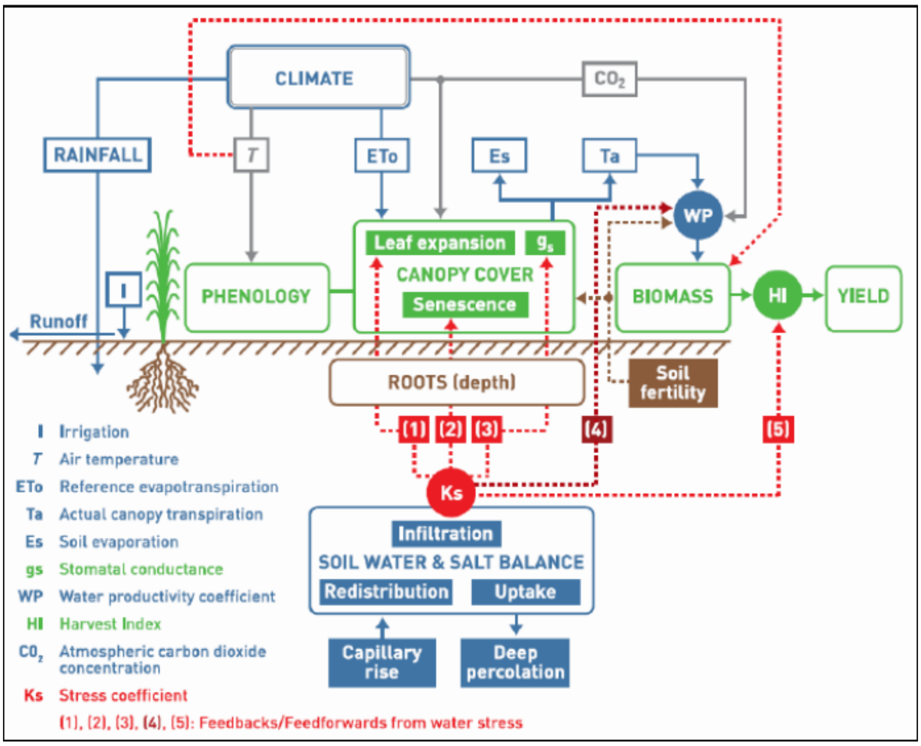

Figure2: flowchart of AquaCrop model showing the main components of the soil-water-plantrelationship
Source: [24]

b. Methods

3.2.1.Evaluation of climate models' ability to reproduce Bohicon climatology

The Taylor diagram [21] applied to the standardized monthly temperature and precipitation series is used to assess the ability of climate models to reproduce the climatology of the study area and to quantify the climate change impacts. According to the literature, the Taylor diagram is a two-dimensional diagram that allows seeing the link between the observed and simulated data from three concise statistical parameters such as the correlation (R), the mean squared error (RMSE), and the standard deviation. Let On and Mn be the observation and the model of respective mean and standard deviation, μ1, σ1 and μ2, σ2 with n = 1, 2,3, ... N. N being the number of observations. The calculation formulas for the statistical parameters R and RMSE are given by the following relations:

$$R = \frac{\frac{1}{N}\sum_{n=1}^{N}(O_n-\mu_1)(M_n-\mu_2)}{\sigma_1\sigma_2} \quad (1)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(O_n - M_n)^2} \quad (2)$$

The model reproduces the climatology better if the value of R is higher and that of the RMSE is*lower*

3.2.2.Evaluation of climate models' ability to reproduce Bohicon climatology

To understand which of the models will reproduce the seasonal climate variability at Bohicon, the seasonal pattern of mean temperature and precipitation simulated by the ten (10) regional climate models during the period 1981-2000 were compared to the observed data.

3.2.3. Climate change assessing

To assess the expected climate changes of the various parameters for the 2030 and 2050 horizons, taking into account the evolution profile of Co_2 in RCP4.5 and RCP8.5. Data from climate models that were found to be robust and consistent in reproducing the climatology of the study area through cross-analysis of the Taylor diagram and seasonal regimes were used. The expected temperature changes were calculated from the difference between the mean annual temperature of the control period (1981-2000) and that of the future (the two horizons). As for precipitation, it's a rate of annual precipitation variation for the 2030 and 2050 horizons compared to the average annual precipitation for the monitoring period which is calculated using the following formula [22].

$$\mathbf{Taux} = \frac{100*(\overline{P_{ti}}-\overline{P_t})}{\overline{P_t}} \quad (3)$$

Where$\overline{P_t}$, denotes the average annual precipitation over the control period (1981-2000) and$\overline{P_{ti}}$, the average annual precipitation in year i for the horizons of 2030 and 2050.

3.2.4. Evaluation of climate model's impacts on maize

The impacts of climate change on maize are assessed on cycle length and yield as follows:

(i) The impacts on the cycle duration were evaluated from the Growing degree days. Indeed, for plants, the passage from one phenological stage to another depends on the Growing degree days. The growing degree day is related to the heat build-up which allows an estimate of how long a plant will develop. However, an increase in temperature could impact the length of the plant's cycle [23]. In this context, let GDD be the number of Growing Degree Days necessary for a crop to complete its cycle.

$$GDD = Lo * (T_{mean} - T_{base}) \quad (4)$$

L_0, is the initial duration of the culture's development cycle. By making a change in variable, Equation (4) can be expressed as Equation (5). Let ΔT be the increase in average temperature due to global warming and ΔL a possible reduction in the length of the crop cycle. Therefore, Growing Degre Day (GDD) becomes:

$$GDD = (T_{mean} + \Delta T - T_{base})\ x\ (L_0 - \Delta L) \quad (5)$$

Based on equations (4) and (5), it emerges that:

$$\Delta L = \frac{L_0 \Delta T}{T_{mean} - T_{base} + \Delta T} \quad (6)$$

L_0 is 90 days, for the variety used in this study, ΔT is the expected mean temperature ($T_{mean)}$ increase in the 2030 and 2050 horizons, and T_{mean} is the mean temperature during the period of crop development. They arecalculated over the growing season which runs from April to July (main rainy season). Tbase is the basal temperature of maize. In this study we have used 8 °C for Tbase already integrated in the AquaCrop model.

(ii) To assess the impacts of climate change on yields, the simulations are done using the AquaCrop model. It makes it possible to determine the probable impact of weather conditions on agricultural production. The AquaCrop version 6.1 culture model is used. The yield simulation is done in the calendar days for the historical period and in degree growing days for the two chosen horizons: 2030 and 2050. The sowing dates chosen during the maize yield simulations have been the days that appear in the first fifteen days of April determined by the AquaCrop model. Concretely, the impacts are assessed by determining the relative variation in maize yields predicted by each regional climate model for 2030 and 2050.

3.2.5. Parameterization of the Aqua Crop model

Parameterization of the AquaCrop model is an inevitable step for the simulation of crop yields. It consists in setting certain non-conservative parameters in the culture, soil and management files (not shown) to approximate the simulated yields to those observed. The yield data observed from 1996 to 2005 by the Direction of Agricultural Statistics (DSA) of Benin are used to perform the parameterization ofthe model and the other for validation. To evaluate the performance of the AquaCrop model, the square root of the Normalized Mean Squared Error (NRMSE) was used. The NRMSE was calculated from the following formula.

$$NRMSE = \frac{1}{\bar{O}}\sqrt{\frac{(S-\bar{O})^2}{N}}x100 \qquad (7)$$

Where $\bar{O}$ denotes the observed average yield, S is the simulated yiel,d and N is the total number of observations. A simulation can be considered excellent if the NRMSE is less than 10%, good if it is between 10 and 20%, acceptable between 20 and 30% and poor when it is greater than 30% [24]. The period of observed yield data chosen for the evaluation of the model is 2008-2014. The variation in maize yields for the 2030 and 2050 horizons is made by calculating the relative deviation of the simulated yields for the 2030 and 2050 horizons compared to the average yield for the control period: the following formula is used [25]:

$$\Delta R(\%) = \frac{R_{fi}-R_h}{R_h}x100 \qquad (8)$$

WhereΔR is the relative deviation of yields for the 2030 and 2050 horizons compared to the control period (1981-2000);R_{fi}, the yield from year i to 2030 or 2050 and R_h, the average yield for the control period (1981-2000).

IV. Results

a. Evaluation of climate models' ability to reproduce Bohicon climatology

Figures 3 show the Taylor diagrams of precipitation and temperature, respectively. In the case of precipitation, the correlation coefficients of NCC, CNRM, MIROC and MOHC are greater than 0.9 and the RMSE is varying from 0.7 to 1 with standard deviations ranging from 1.5 to 2. For the mean temperature, NCC, ICHEC, CSIRO, MIROC, MOHC and MPI models present very good correlation coefficients, generally greater than 0.9 and values of RMSE ranging from 0.40 to 0.5 and standard deviations ranging from 0.9 to 1.3.

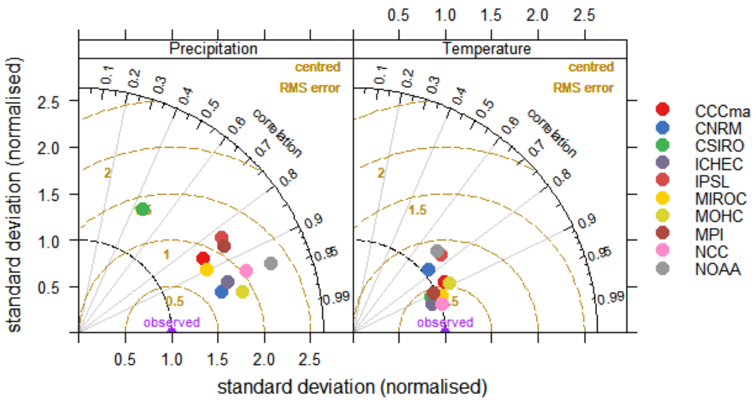

Figure 3. Taylor diagram of temperature and precipitation for ten regional climate models

Figures 4 show the seasonal patterns of precipitation and temperature. It can be observed in the seasonal temperature that the regime is represented by almost of the models studied in the present study. The maximum and minimum values of temperature observed respectively in March and Augustin Bohicon are reproduced. The seasonal rainfall pattern is not reproduced by the majority of the regional climate models. The NCC, MIROC, MOHC, MPI and ICHEC models have partially reproduced it. These models fail to reproduce the extreme values. Based on the results of the cross-analysis of seasonal regimes and Taylor digraphs of precipitation and mean temperature, it is important to retain that among all the studied models, the NCC, MOHC and MIROC models reproduce more correctly theBohicon's climatology. They will be used to assess the expected changes in climate for 2030 and 2050 horizon.

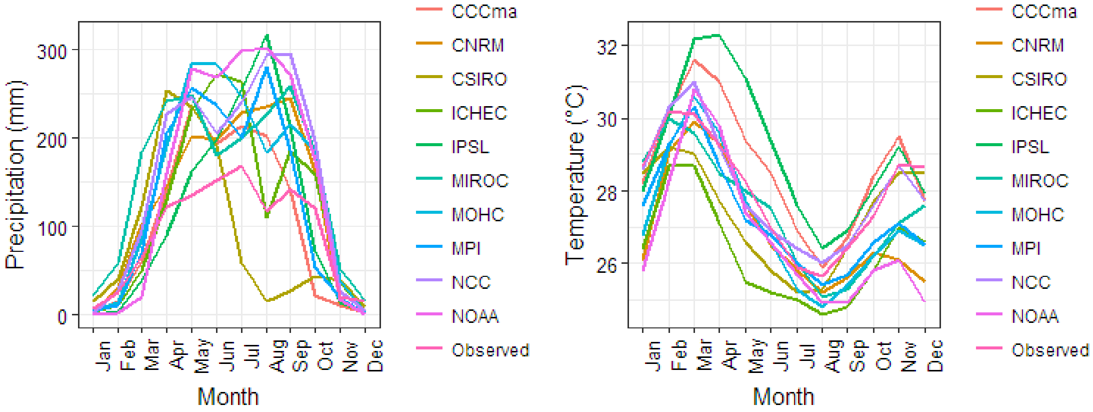

Figure 4. Seasonal regimes of rainfall (left) and temperature (right) in Bohicon for all RCMs models and observed data

The results obtained for the variation in mean temperature and precipitations are presented in Figure 5. Temperature variation is on left and a precipitations variation is on right of Figure 5. These results show that an increase in the mean temperature for the 2030 and 2050 horizons in the municipality of Bohicon is projected by all models (NCC, MOHC, and MIROC). The mean temperature by 2030 will increase an average of 0.8 ° C to 1.4 ° C for RCP4.5 and from 1 ° C to 1.8 ° C for RCP8.5. Warming is expected to become more pronounced by 2050. The average will vary from 1.3 ° C to 2.3 ° C for RCP4.5 and from 1.7 ° C to 2.8 ° C for RCP8.5**.**According to the variation of precipitations, rainfall will be highly variable over the 2030 and 2050 horizons in the study area. By 2030, the MIROC model predicts average precipitation, regardless of the scenario, with an approximately 20% increase in annual precipitation compared to the monitoring period. However, the MOHC and NCC models predicted invariable situations. In addition, by 2050, annual precipitation increases of approximately 11 to 16% under the RCP4.5 scenarios are forecasted by the MIROC andMOHC models and of 12 to 18% under RCP8.5. In contrast, the NCC model does not predict any variation in annual precipitation over this horizon, both at the level of RCP4.5 and RCP8.5.

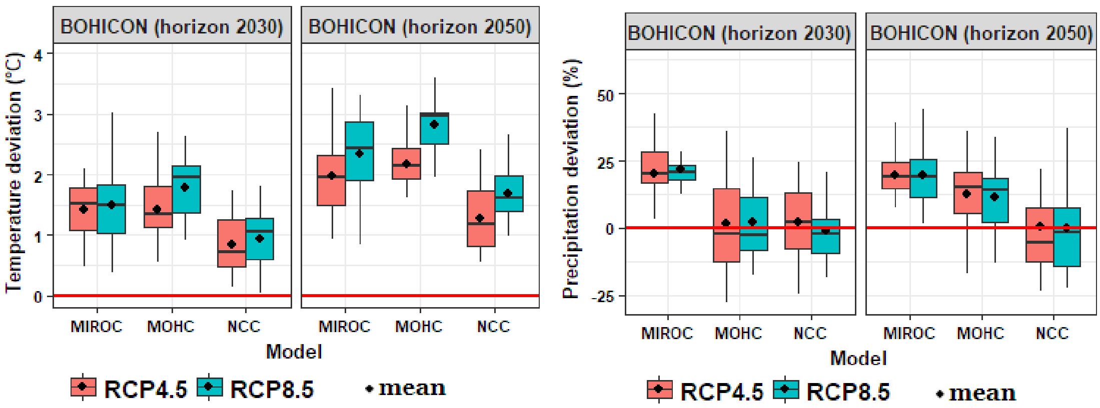

Figure 5.variation of the average temperature (left) and the relative variation in precipitation(right) in Bohicon for the 2030 and 2050 horizons according to RCP4.5 and RCP8.5.

b. Evaluation of climate impacts on maize in Bohicon.

The effect of climate change on the length of the maize cycle is shown in Figure 7. Projections predict a reduction in the length of the maize cycle by 2030 and 2050 in the municipality of Bohicon, Brazil. All models project a reduction of at least four days in cycle length by 2030 and 2050, regardless of the scenario. The reduction projected by the MIROC and MOHC models by 2050 was greater. It can reach approximately 10 days for RCP4.5 and 12 days for RCP8.5.

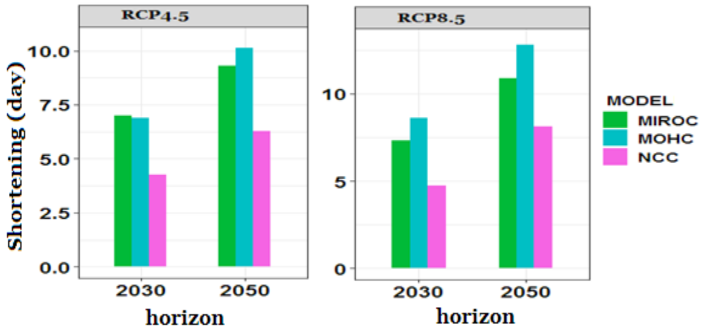

Figure 6.Shortening of the cycle length of the DMR ESR W variety by 2030 and 2050 in RCP4.5 and RCP8.5.

The model Aquacropparametrization is an inevitable step for the simulation of crop yields. It consisted in setting a certain no conservative parameters in the crop, soil and management files for the AquaCrop in order to approximate the simulated yields to the observed. In this study, the correlation coefficient between the observed and simulated yields is 0.46 (Figure 7). Again, The NRMSE value is approximately 20.9%. These results show that the model AquaCrop, is efficient to simulate a maize yield in Bohicon.

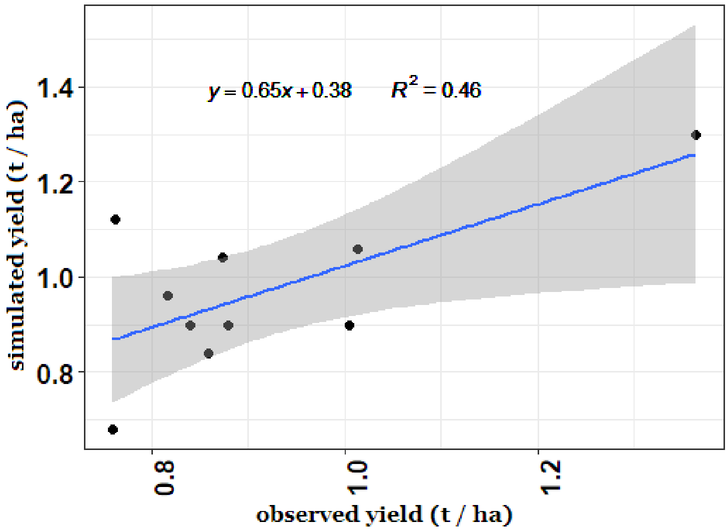

Figure 7. Correlation between the observed and simulated yield by AquaCrop model

The variation of the simulated yield for all models selected in this study is shown at figure 8. In average, All models agreed on decline in maize yields by 2030 and 2050 horizon, regardless of the RCP (Figure 8). The decreases will vary in the municipality of Bohicon by 2030, on average, from 2.5% in the MIROC model to 4% in the NCC for the two RCP. By 2050, they will vary on average from 2.5% in the NCC to 7% in the MOHC for RCP4.5 and from 8% to 18% for RCP8.5. According to the MOHC model, it is therefore possible to expect yield reductions of approximately 14% on average in RCP8.5 by 2050.

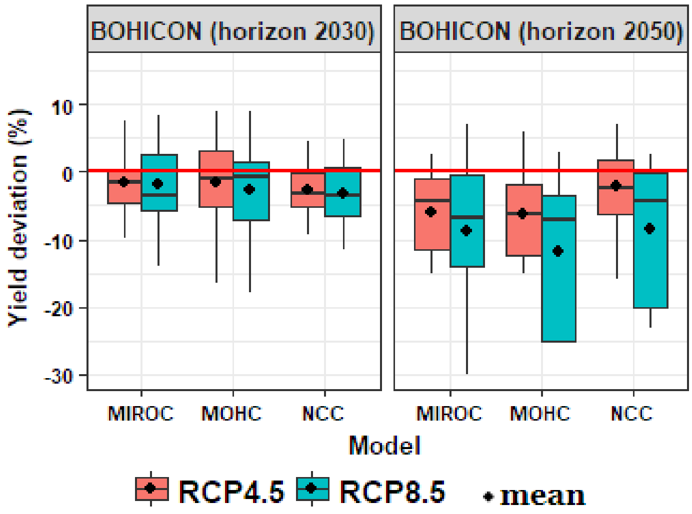

Figure 8.Relative difference in maize yields in Bohicon for 2030 and 2050 horizon.

V. Discussion

At the end of the evaluation of the regional climate models, all models that reproduced the Bohicon climatology unanimously predicted an increase in the average temperature by 2030 and 2050, regardless of the scenario. By referring to the average temperature variations predicted by these models, it can be said that the Bohicon District will record significant thermal changes by 2030 and 2050, which will exceed those it has experienced in the past. The increase will vary from 1.3°C to 2.3°C for RCP4.5 and from 1.7°C to 2.8°C for RCP8.5 by 2050. [13] Obtained similar results in their West Africa agriculture and climate change study based on four global climate models forced under greenhouse gas emission scenarios B1, A1B, and A2. The results obtained confirm those of [26-28] who found that by 2050, the rise in mean temperature would be from 2.4 to 3.5 °C and around 4.02 °C by 2100, also those obtained in the second Initial National Communication (CNI) of the country carried out on climate change in 2011 [29].

The impacts of climate change, as highlighted by the Intergovernmental Panel on Climate Change in their 2013 report [30], vary from one region to another in the occurrence of rainfall. Thus, the models do not predict in a consensual way, the rainfall variability for Bohicon. An increase in annual precipitation of approximately 20% is predicted by the MIROC model and a situation without change for MOHC and NCC by 2030; on the other hand, MIROC and MOHC predict increases by 2050. There is no unanimity in the results of the annual precipitation changes in the area. According to some authors, precipitation will not vary practically [28] and will decrease by 100 mm to 200 mm by 2050 according to the CSIRO model used by [13]. Therefore regional climate models do not reproduce all regional or local climates. The variability of the results obtained on the trend of precipitation in the study area would therefore be due to the fact that the research was carried out at different scales by the authors and using different regional or global climate models.

According to the Organization for Economic Co-operation and Development (OECD), agriculture is most influenced by climate change [31]. Indeed, higher temperatures decrease crop yields, and a change in rainfall patterns increases the likelihood of short-term crop failure and lower long-term productivity [32]. Rising temperatures lead to lower yields and shorter crop cycles [33]. In Bohicon, the changes identified by 2030 and 2050 will cause a reduction in the length of the DMR ESR W maize variety by a minimum of four (04) days and a maximum of 10 to 12 days. This tendency to reduce the length of the cycle was also revealed by [34] in their study. According to the National Action Program for Adaptation to Climate Change [35], an increase in temperature leads to shortening of the vegetative cycle of crops. This finding confirms the results of the present study. The consequence of this shortening of the length of the cycle is decreased in maize yields unanimously predicted by MOHC, MIROC, and NCC by 2030 and 2050. The certainty of the decrease in maize yields should therefore be noted because the results show the unanimity of several authors in the study area [13, 36].

VI. Conclusion

The objectives of this study were to: (1) assess the capacity of climate models to reproduce climatology, (2) show the expected climate changes for the horizon 2030 and 2050, and (3) assess the impacts of these changes on the cycle duration of the DMR ESR W maize variety and its yield in Bohicon (South Benin). The main conclusions are summarized as follows.

(a) Among the ten (10) models studied, only three (MIROC, MOHC, and NCC) reproduced Bohicon's climatology.

(b) An increase of 1.8 ° C in the mean temperature is observed in RCP8.5 by 2030 and 2.8 ° C by 2050.
(c) Future projections for precipitation variability vary from one climate model to another. Thus, regardless of the scenario considered, the MIROC model predicted an increase in precipitation of approximately 20% by 2030. However, the MOHC and NCC models predict stability, and do not change.

(d) The DMR-ESR-W maize variety will beinfluenced by future projections. Regardless of the model and scenario considered, a shortening of its cycle of at least four days is expected. This shortening can reach 10–12 d in the MIROC and MOHC models. Yield reductions of 8 to 14% in RCP8.5, on average, would be expected by 2050.
In future work, these studies will be extended toother crops using a large number of climate models and approaches to assess the impacts of climate change.

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